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MEASURING THE DETONATION VELOCITY OF EXPLOSIVES

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Canadian Explosives Research Laboratory

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by

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ABSTRACT

Detonation velocities of explosives were determined using a linear resistance probe powered by a variable constant current power supply. All signals were displayed on a digital storage scope and permanently recorded on magnetic disc. The report outlines the procedure for obtaining accurate detonation velocities on various explosives.

Key words: Detonation velocity, Linear resistance probe, Constant current supply, Commercial explosives, Detonating cord

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MESURE DE LA VITESSE DE DÉTONATION DES EXPLOSIFS

par

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RÉSUMÉ

Nous avons déterminé les vitesses de détonation des explosifs au moyen d'une sonde alimentée par une charge à courant continu variable, utilisée pour prendre les mesures de résistance linéaires. Tous les signaux ont été traduits sur un oscillographe numérique et enregistrés de façon permanente sur disque magnétique. Dans le présent rapport, les auteurs décrivent dans la détail la façon de procéder pour obtenir des vitesses de détonation précises avec divers explosifs.

Mots-clé: Vitesse de détonation, sonde utilisée pour les mesures linéaires de la résistance, charge à courant continu, explosifs commerciaux, cordeau détonant

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MEASURING THE DETONATION VELOCITY OF EXPLOSIVES

INTRODUCTION

In routine work, detonation velocities of commercial explosives are normally determined with the use of ionization probes. This method utilizes the detection of the ionized detonation wave front to start and stop a counter. With this measured time interval and a given separation of the probes, an average detonation velocity can be computed.

The drawback of this method is in the minimal data that it provides. It gives no history of the velocity of the detonation front. What is desirable is information from which one can determine the time to steady state detonation velocity, a decay or build-up to detonation, and any other disruptions that may occur to the detonating process.

THE PROBE AND ASSOCIATED INSTRUMENTATION

With the advent of digital storage oscilloscopes, the task of obtaining a time profile of the behaviour of the detonation front is greatly simplified. No longer is it necessary to use photographic equipment in conjunction with a conventional analogue oscilloscope to capture the event. The main components that are presently being used to obtain such data will now be described.

Basically, a linear resistance probe and two instruments are required; a constant current supply and a digital oscilloscope. These items are shown in Fig. 1.

The linear resistance probe is constructed using resistance wire and hypodermic needle tubing. The 0.078 mm diameter wire is skip wound nylon Moleculoy (1) resistance alloy having an electrical resistance of 2.98 ohms per centimetre. Usually this wire is inserted in aluminum tubing. However, stainless steel and brass tubes are also often used. The aluminum tubing (2) has an outside diameter of 0.584 mm and a wall thickness of 0.038 mm while the stainless steel tube

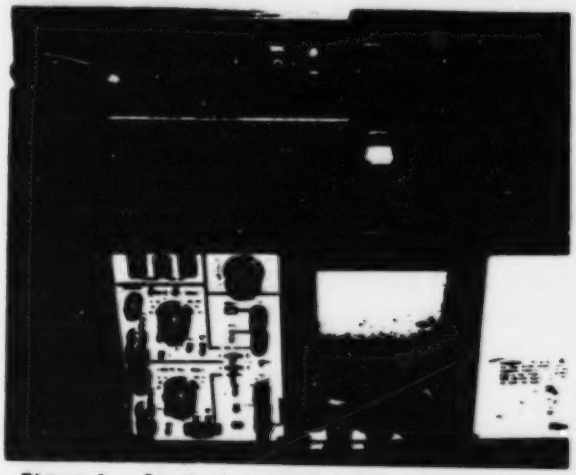

Figure 1 - Constant current supply, probe and digital storage oscilloscope

(3) has a 0.559 mm outside diameter and a 0.127 mm wall thickness.

The first step in assembling a probe in to cut a tube to the required length. On one end, a 5 to 10 cm length of insulated wire (30-gauge) is partly stripped and attached to the tube using a wire wrapping tool. This will serve as the electrical ground connection. Carefully insert the resistance wire in this end of the tube, until it protrudes a few centimetres from the other end. Using a set of long nose pliers, collapse this end of the tube over a distance of about one centimetre to produce an electrical short. Excess wire is then trimmed and the collapsed section folded over to ensure a strong mechanical connection. The resistance wire can now be cut from the spool so that it extends about 5 cm beyond the tube. A 2 to 3 cm length of shrink-tubing is then pushed over the ground connection so that it protrudes about 3 cm past the end of the metal tube. This guides the resistance wire away from the end of the metal tube, thereby reducing the possibility of a short circuit. At this stage an electrical resistance check will pinpoint any undesirable short or open circuits. If any such defects are

found and cannot be corrected, the probe should be discarded.

The constant current supply has been described in reference (4). Basically, current and voltage and available at the banana plugs when the BNC selector switch is in the OFF position. Moving the switch either to the I or the V position will result in the current or the voltage source appearing at the BNC terminal. The thumbwheel selector switch allows current selection in 0.1 mA steps from 0 to 99.9 mA and voltage selection in 10 mV increments, from 0 9.99 V. In the constant current mode, the supply will operate at about 18 V maximum. Therefore, when setting the constant current for a given load, make certain that Ohm's Law is being obeyed. For example, if the load is 360 Ohms, then the maximum current that the supply will deliver is 50 mA (18 V/360 Ohms). Any setting above 50 mA will not result in a corresponding current output and the detonation velocity value obtained will be in error. In any event, it is best to keep the current as low as possible to avoid heating the explosive or overheating the wire and affecting its electrical resistance.

Digital storage oscilloscopes are now widely available and facilitate data analysis in several aspects. The event is captured in memory and displayed on the CRT screen. Using cursors, accurate voltage and time measurements can be read directly from the screen. Some oscilloscopes have facilities for transferring this digitized data to computers or to dedicated discs. Once stored, the data can be manipulated as desired.

When a signal is obtained with a conventional oscilloscope, the following equation, as given in reference 5, can be used to determine the detonation velocity.

$$D = 10000[(X/Y)/Ir] \tan a \qquad (1)$$

where D = velocity, mm/μs
X = scope gain, v/cm
Y = scope sweep, μs/cm
I = probe current, mA
r = unit probe resistance, ohms/cm
a = the angle of the trace as measured from the time axis, in degrees

When a digital oscilloscope having no graticule is used to determine the detonation velocity of an explosive, a slightly modified equation can be derived. From Ohms Law,

$$V = IR \quad \text{or} \quad V = Idr$$

where V = the voltage across the probe, V
I = the probe current, mA
R = the probes total resistance, ohms
r = unit probe resistance, ohms/cm
d = probe length, cm

The detonation velocity is then simply,

$$D = d/t$$

where t, measured on the oscilloscope trace, is the duration of the event as witnessed by the probe. Substituting d = V/Ir in the above equation gives the detonation velocity as,

$$D = (V/Ir)/t$$

As already mentioned, the probe's unit resistance is 2.98 ohms/cm or 0.298 ohms/mm. Substituting this value and the 50 mA probe current used in routine testing, the above equation reduces to,

$$D = 67.1(V/t) \qquad (2)$$

where (V/t) is simply the slope of the trace. With V in volts and the time t entered in milliseconds the detonation velocity D will be in m/s.

EXPERIMENTAL

The most common application of this method is for determining the detonation velocity of commercial explosives. However, it can also be used for monitoring gap tests or deflagration to detonation transitions in explosive samples. Outlined below are several tests that were used to demonstrate the performance of this apparatus.

Shown in Fig. 2 is the arrangement for determining the detonation velocity of cartridged, commercial explosives. To physically support the probe, it is carefully taped to a narrow piece of wood ensuring that it lies flat and in a straight line. The cartridge of explosive is then taped in contact with and centered on the probe and the wooden support. By having the probe longer than the explosive sample the full history of the event can be witnessed . This assembly is now ready to be hung in an explosion tank. An electric detonator is inserted in the end of the explosive close to the shorted end of the probe and the

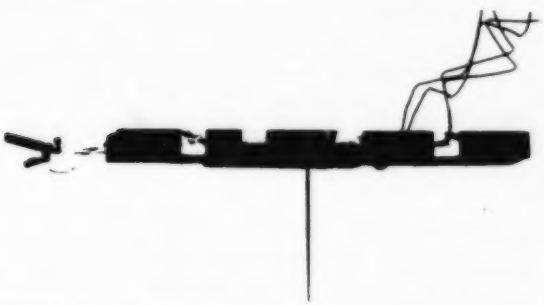

Figure 2 - Detonation velocity probe fastened to a cartridge of a commercial explosive

detonator wires are taped to the support to avoid placing any stress on the detonator. The signal wires are then taped to the other end of the support and connected to the probe.

To obtain the maximum information from a single trial it is best to use as long an explosive sample as possible, with the sample being formed by a train of cartridges. When using 200 mm long cartridges, three should be taped end to end for a total length of 600 mm. With 300 mm and 400mm long cartridges, two are taped together to form a 600 mm and 800 mm length, respectively. With all these configurations, the mass of the explosive sample must never exceed the limit for the explosion tank being used. In all of the above cases, two probes can also be used on each sample either for the purpose of comparing surface velocity to inside velocity or simply for comparing values in the same zone.

The oscilloscope should now be readied to capture the event. With the constant current power supply connected to the probe and the oscilloscope, adjust the current setting to 50 mA. Then, by switching the input from the dc mode to the ground mode adjust the oscilloscope's sensitivity to obtain a trace that spans as much of the vertical display of the screen as possible. The sweep time or time per point should also be set to obtain a trace that fills most of the screen's width. Once these settings are made, adjust the trigger level and arm the oscilloscope. The sample may now be fired.

During the firing procedure make certain that the oscilloscope is not accidentally triggered. Only the detonating explosive must trigger the oscilloscope to obtain the correct signal.

A typical example of a trace obtained on a digital oscilloscope, having a graticule, is shown in Fig. 3. This signal was obtained by detonating two cartridges, of very similar explosives, taped end to end . Using equation (1) with X = 2 V/cm, Y = 100 us/cm, I = 50 mA, r = 2.98 ohms/cm, tan a = 1.83 V/s, and tan a = 1.90 V/s for the first and second explosives respectively, the corresponding detonation velocities are, 2.456 mm/us and 2.550 mm/us.

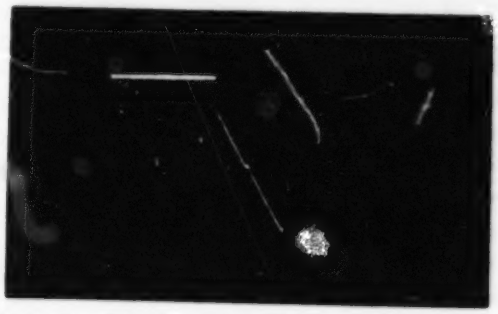

Figure 3 - Signal, obtained on a conventional oscilloscope, of two cartridges of explosive taped end-to-end

Figure 4 shows a typical trace obtained when two, 200 mm cartridges of 32 mm diameter dynamite are taped end to end and detonated. The sharp initial drop in the signal is caused by the detonator overdriving the explosive and simultaneously collapsing the prove. As the steady state detonation velocity is established, the magnitude of the signal's slope drastically decreases and then slightly increases to a constant value. The

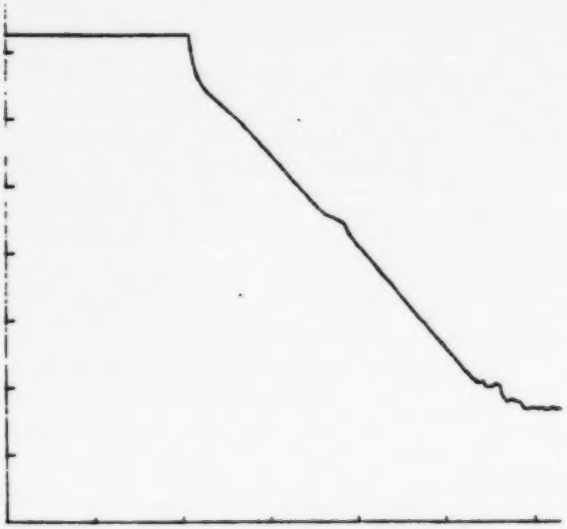

Figure 4 - Signal, obtained on a digital oscilloscope, of two cartridges of dynamite taped end-to-end

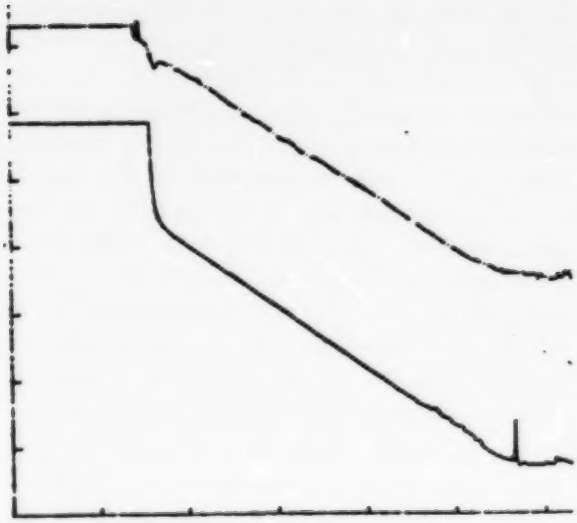

Figure 5 - Signals obtained for a detonating, 19 mm diameter by 600 mm long, cartridge of explosive. The reported average detonation velocity is 2400 m/s

detonation velocity calculated in this area is 3970 m/s. A perturbation in the signal indicates the transition between the two cartridges. Most of the results indicate that steady state detonation in the receptor cartridge is very quickly established as indicated by a long trace with constant slope. The detonation velocity calculated on this second cartridge is 4180 m/s. Calculation of the velocity of detonation should then be based as indicated, on measurements made in the latter part of the donor charge signal and on most of the receptor charge signal. The average of these values are then reported. In this example, the reported detonation velocity would be 4080 m/s.

Tests were also performed using two probes on each explosive sample. Figures 5 and 6 show the results for single, 19 mm diameter by 600 mm long and 40 mm diameter by 400 mm long explosive samples, respectively. The velocities obtained from each signal in Fig. 5 were 2360 m/s and 2450 m/s, with the reported velocity being 2400 m/s, the average of the two. The values determined from Fig. 6 were 4520 m/s and 4590 m/s for an average reported value of 4560 m/s.

As indicated by the above examples and that shown in Fig. 7, both probes give very similar results. Figure 7 shows signals obtained from two probes monitoring the detonation history of two, 32 mm diameter by 200 mm long, cartridges of explosive taped end to end. Following the procedure outline above for calculating the detonation velocity of cartridges taped end to end, the very similar values of 3590 m/s and 3610 m/s were obtained. These results indicate that both circuits are performing equally well. The reported detonation velocity for this sample would again be the average of the two values, 3600 m/s.

Following the same procedure as outlined above and the set-up shown in Fig. 8, the detonation velocity of detonating cord was determined. Figure 9 shows a typical record, from which the detonation to be 6600 m/s.

CONCLUSIONS

A continuous velocity probe in conjunction with a constant current power supply can be used to routinely determine the time histories of detonation events. The detonation profiles obtained with this method and captured on a digital oscilloscope proved to be reproducible. Also, with the slope measurements taken as indicated in the report, the calculated detonation values will not be operator dependent and will be more accurate.

Figure 6 - Signals obtained for a detonating, 40 mm diameter by 600 mm long, cartridge of explosive. The reported average detonation velocity is 4560 m/s

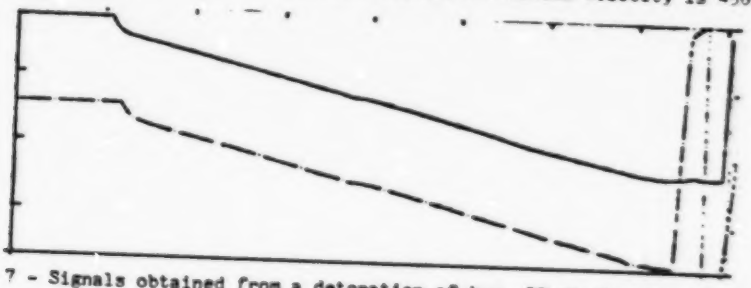

Figure 7 - Signals obtained from a detonation of two, 32 mm diameter by 200 mm long, cartridges of explosive taped end-to-end. The reported, average detonation velocity is 3600 m/s

Figure 8 - Set-up for determining the detonation velocity of detonating cord

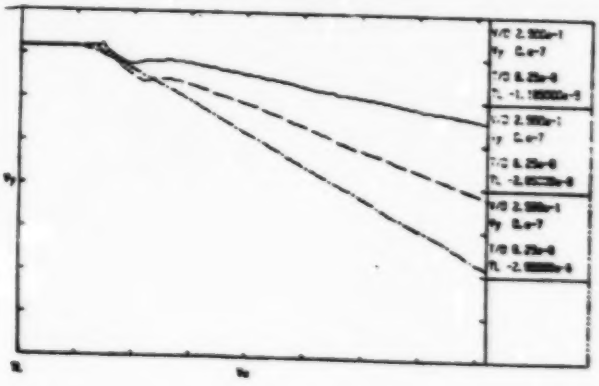

Figure 9 - Typical record obtained from detonating cord. The average reported detonation velocity is 6600 m/s

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